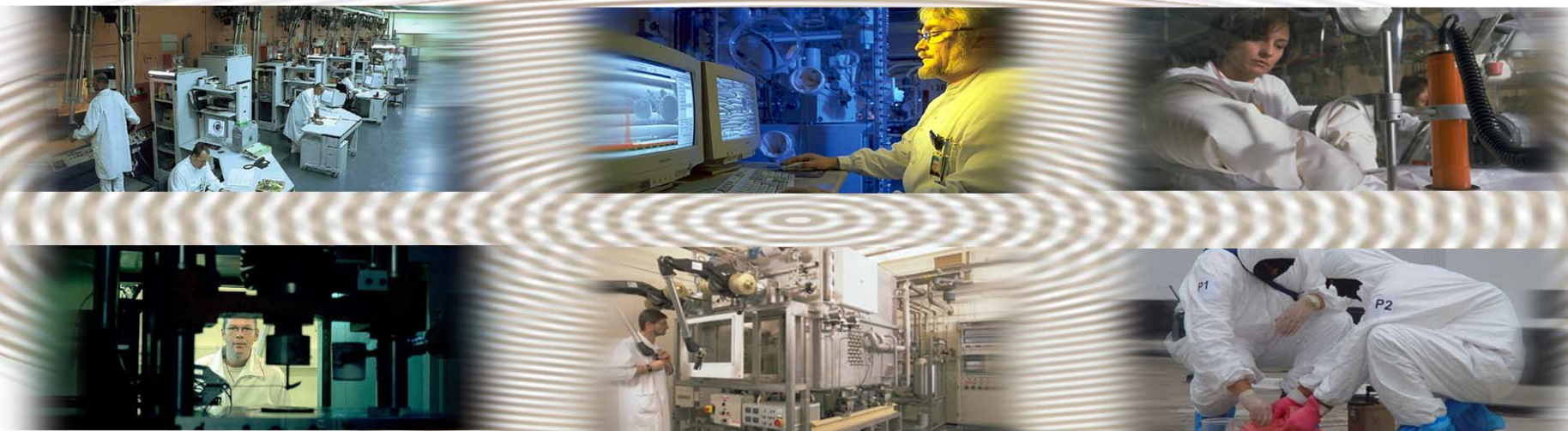


40 years of science
at the



institute for transuranium elements



JRC Mission

The mission of the Joint Research Centre is to provide customer-driven scientific and technological support for the conception, development, implementation and monitoring of European Union policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Community. Close to the policy-making process, it serves the common interest of the Member States, while being independent of commercial or national interests.

ITU Mission

The mission of ITU is to protect the European citizen against risks associated with the handling and storage of highly radioactive elements. ITU's prime objectives are to serve as a reference centre for basic actinide research, to contribute to an effective safety and safeguards system for the nuclear fuel cycle, and to study technological and medical applications of transuranium elements.

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foreword

Anniversaries of Institutes, like those of our own, are a time for looking back and celebrating what has been accomplished, as well as a time to reflect where we are today to prepare for the future.

40 years ago construction of ITU started in the Forschungszentrum, Karlsruhe. At that time, there was great hope that nuclear power would go a long way to solving the world's energy supply, and Europe was enthusiastic to join in the technological effort to bring this to reality. And indeed, as you will read in this booklet, ITU has played an important role in this endeavour. More recently, our aims have included a strong focus on the safety aspects and the disposal of nuclear waste. The Institute is financed by the European Commission, within the Directorate General, Joint Research Centre.

As with our personal lives, long-term aims and ambitions change with time – so it has been with ITU. We are still centered on the actinides, those elements after actinium with a progressive filling of the $5f$ electron shell, and which require highly skilled personnel and a considerable infrastructure and licensing procedures. But we now have multiple goals and objectives, befitting a mature organization living in the beginning of the 21st century. We are here to serve the European citizens, and their demands are many and often complex!

The following pages give you a short overview of some of our abilities and programmes. The first article is a “look back” with an attempt to explain briefly the early history of the Institute. This is followed by a series of articles characterising where we are today, and giving a perspective for the future.

Of these articles the first three, **Nuclear Safeguards**, **Measurement of Radioactivity in the Environment** and **Nuclear Forensic Science** can be truly said to be serving directly the citizen, and are also major factors in the enlargement of the

European Union set for 2004. **Alpha Immunotherapy** uses our competence in alpha-emitters to search with the medical profession for ways to treat certain tumours with alpha-emitters. Underpinning much of our work with actinides is basic research, and this continues to provide surprises – as you will read in connection with **Superconductivity in Materials Containing Plutonium**. We then present a series highlighting our efforts on safety and characterisation of the fuel cycle: **Safety of Nuclear Fuels**, **Thermophysics and Nuclear Materials Science** and **The Transuranus Code**. The last theme touched is the problem of nuclear waste: **Radioactive Waste Management** and **The Minor Actinide Laboratory**, where the latter gives a foretaste of the possibility of transmutation of the nuclear waste. Finally, we present basic research on a possible new method for such a technology, this time using **Laser Transmutation**. Within these you will find an interesting blend of basic and applied research that makes the Institute the stimulating and challenging place we see today.

We are well prepared to face the diverse challenges of actinides in this new century. Much of the reason for this can be directly ascribed to the vision of those who have gone before, and this birthday gives us a chance to say thank you to the many experienced staff responsible for our readiness. To the young staff, many of whom have joined us in the last five years, I welcome them to the party.

I ask all of you to join me in celebrating both our accomplishments as well as the promise of future successes, which will be yours to deliver.

Gerard H. Lander
Director of ITU

historic review of the past 40 years

The Institute for Transuranium Elements in Karlsruhe is an international research establishment, set up to investigate the technical applications, the safety and environmental aspects of elements ranging in the Periodic Table beyond element 92, Uranium. It is operated by the European Commission and is part of its Joint Research Centre (JRC).

The answer to the question “Why is it located at the site of the German Research Centre north of Karlsruhe?” makes an interesting story:

Not many years after the end of the second World War, the leading figures in German nuclear research, among them Werner Heisenberg, Carl-Friedrich von Weizsäcker and Karl Wirtz, began to work out a national nuclear research and development strategy. A principal characteristic of this strategy was the use of plutonium-239 as the primary source of energy*. It was felt that construction and operation of a plant for uranium-isotope enrichment would be by far too costly for the impoverished (West-)German post-war economy, and that the chemical separation of plutonium from uranium in a reprocessing plant might be technically easier and cheaper than isotope separation via, for example, gaseous diffusion.

But it was not until May 1955 that the occupation regime in Germany came to an end and that the allied powers gave the green light for the resumption of large scale nuclear research and the development of a nuclear industry. This was hailed with great enthusiasm, and Karl Wirtz describes in his autobiography “the wonderful feeling” among the members of the German delegation to the First Geneva Conference on the Peaceful Uses of Atomic Energy in autumn of 1955. For them “a new era was about to dawn”. On June 16, 1956, the documents pertaining to the founding of the Research Centre were signed, and immediately thereafter the foundation stone was laid in the Hardtwald, north of Karlsruhe (Germany).

* Already in 1940, C.F. v. Weizsäcker had pointed out that the isotope 239 of element 94 might be fissile with fast and thermal neutrons and that the resulting neutron yield would suffice to maintain a chain reaction.

The first of the seven points of the high priority-list for the first German “Atom-Programm”, prepared in January 1957 by the Federal Government, was a “well-equipped Plutonium-Institute” to be erected in Karlsruhe. It should serve “to study the technology of production of plutonium-based fuel elements”. The competent authorities foresaw five million DM for investments and one million DM for annual running costs. The project quickly gained momentum, and at a meeting of the planning group in November 1957, one of the later directors of the centre, Walter Schnurr, suggested to change its name to “Institute for Transuranium Elements” (ITU).

When specialized engineering firms (Leybold, Uhde, Lurgi, later also St. Gobain) began a detailed planning, they concluded, that the programme foreseen for ITU would require investments of at least 30 million DM (status 1958). This was far beyond the amount which the Federal Ministry for Atomic Affairs was willing to accept. Thus, in May 1958, one of the members of the Board of Directors of the Centre, Otto Haxel, suggested an approach to the newly established Commission of the European Atomic Energy Community (Euratom, founded in March 1957) for a contribution in order to help to finance the Institute.

The first reaction from Brussels was positive, and in July 1958, the Euratom Director General for Research and Development, Jules Guéron, came to Karlsruhe in order to discuss the matter. He made it clear, right from the beginning, that Euratom was very much interested in the Institute, but only, if it was fully integrated into the European Commission’s Joint Research Centre and if its programme was in agreement with the Communities research policy, with all results obtained being made available to all Member States. The latter condition caused some initial irritation within the German nuclear establishment, but Siegfried Balke, the Federal Minister for Atomic Affairs, declared the acceptance of the Euratom proposal as a German contribution to European unification and gave his

agreement. In further deliberations it was decided that a limited number of well-defined small research tasks should be carried out at the Institute upon request of the German partners.

In October 1961, the Commission nominated Jean Blin the first Director. The 39 years old former head of the “Laboratoire d’Etudes sur les Combustibles Irradiés” of the French Commissariat à l’Energie Atomique (CEA) in Saclay was an excellent specialist in the field, with charisma and a gift of leadership. He worked out a framework programme for the Institute and supervised the planning and construction work in every detail from November 1962 on. The official laying of the corner stone took place on 1 April, 1963.



By that time, leading staff members, most of them between 30 and 35 years of age, had been recruited and sent to laboratories in Europe and in the US (Mol, Liège, Fontenay-aux-Roses, Saclay, Cadarache, Harwell, Hanford, Argonne and Berkeley) in order to become familiar with the peculiarities of handling and doing research with highly radioactive materials. They were called back to Karlsruhe in the course of 1964, when the first laboratories of the Institute became operational.

The Institute had obtained 2 kg of (US-)plutonium at a price of 45 \$/g as a starting material. The first sample of this plutonium was introduced into one of the glove boxes in wing A on 10 February, 1965. On 6 April of the same year, celebrities from science, industry and politics together with the Institute staff assembled in the entrance hall for a ceremony, at the end of which Pierre Châtenay, the President of the Euratom Commission, opened the door of access to the controlled area of the Institute.



*Pierre Châtenay opened
the door to the laboratories*

historic review

The first interesting results of the work of the highly motivated research teams were obtained in a surprisingly short time. Most spectacular was the fabrication of 2100 metallic fuel pins for the French zero-power reactor Masurca in Cadarache within nine months in 1966/67, involving 187 kg of highly pure ^{239}Pu .

During these years of nuclear euphoria, numerous prominent persons visited the Institute, among them the President of the Federal Republic, Heinrich Lübke, the Federal Minister for Finances, Franz Joseph Strauss, The President of the European Commission, Jean Rey, the Prime Minister of the Land Baden-Württemberg, Hans Filbinger, and the Federal Minister for Research, Hans Leussink.



German President Heinrich Lübke and the Director of ITU Jean Blin.

In 1968, after being decorated with the “Bundesverdienstkreuz” for his excellent services, Jean Blin returned to the CEA, and on 30 May, 1969, Roland Lindner, Interim Director of the Ispra Research Centre and Head of its Chemistry Department, was introduced as the new Director. Roland Lindner played an important role in defending the existence of the Joint Research Centre in the following period of challenges, which ended only in February 1973, when a proposal of Research Commissioner Ralf Dahrendorf was accepted by the Council of Ministers that opened the way to a broadening of the scope of the JRC programmes.

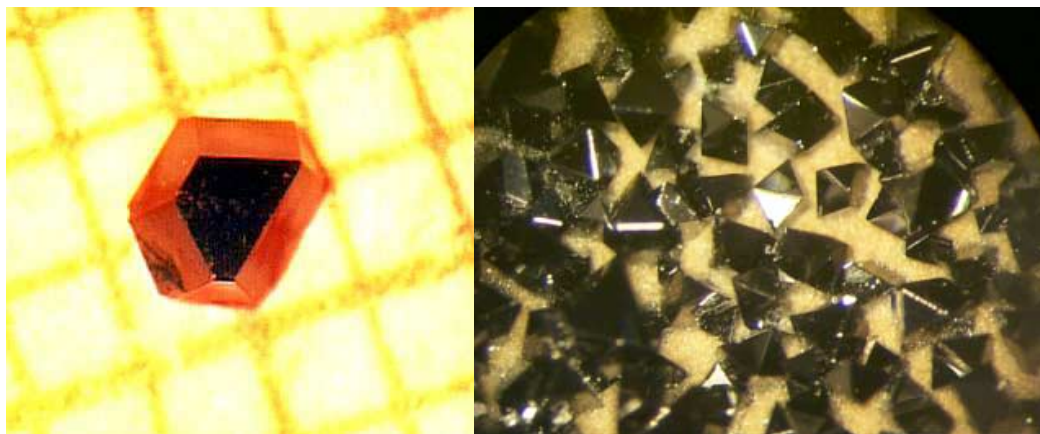
The ensuing restructuring process within the Joint Research Centre had little effect on the Institute. Its principal tasks remained unchanged, nuclear.

The start of the basic research effort at ITU can be traced to efforts of Werner Müller and his associates starting in the 1960s with the purification of the actinide metals. The focus was thus on chemistry to prepare well-characterised and pure samples. Not surprisingly, once the samples were available many physicists started to have an interest in them and their properties. This synergy between the need for rigorous chemical specification and physics experimentation has continued to govern the basic research effort. High-quality single crystals were produced in the early 1980s and a fruitful collaboration established between CEA-Grenoble, ETH-Zurich, and ITU. Many pioneering experiments were performed, but with a change of emphasis to actinide compounds rather than the metals in an attempt to understand the hybridization and localization of the elusive 5f electrons, which give such special properties to the actinides. Gradually over the last 20 years a full suite of capabilities for physical characterization of the samples, together with efforts in photoemission and high-pressure research, have been established at ITU and in 2000 these were for-



Roland Lindner

mally recognized as the “Actinide User Laboratory” funded from outside the JRC to bring European researchers into ITU and perform their experiments under the general commitment to maintain and spread the competence in actinide science in Europe.



With the decline of interest in fast breeder technology and the opposition of some member states to nuclear power, ITU was no longer able to maintain a strong effort in innovative fuel and reactor technology. Instead the emphasis turned to the safety of nuclear fuel and the general questions surrounding waste management. In the safety of nuclear fuel the development of the TRANSURANUS code, which predicts many properties of an operating fuel element, was an important contribution and has become even more so as we look to the expansion of the European Union in 2004 with the inclusion in the EU of many Soviet-designed reactors. The high-temperature characterization of oxide fuel is of special concern in nuclear fuel safety, both from a fundamental point of view (for example

in understanding the so-called rim effect), as well as to the power companies, for whom the consequences of higher burn-up need to be understood before economic factors can be judged. Thus, new capabilities in high-temperature thermodynamics have built on the earlier efforts. ITU’s hot cells and ability to perform tests on irradiated fuel, expensive though they are to maintain, have become crucial technologies and have generated much of the outside income for ITU’s balance sheet in the last 15 years. As well as the high-temperature properties, which have a long tradition of excellence at ITU, the materials science programme has focused on the problems associated with long-term storage of nuclear fuels and performed research on what is generally called the “near field” aspect of waste disposal. For example, a pertinent question is what happens when the stored radioactive fuel comes in contact with water, and how does the radioactivity effect the dissolution of the fuel?



historic review

Rather than store the highly-active spent fuel for thousands of years an alternative strategy considered in many laboratories around the world is the possibility for first “separating” out the minor actinides (Np, Am, and Cm) and then “transmuting” them to other elements in a high neutron flux. ITU has built a capability in both these areas. In most cases the effort is a collaborative one, for example, investigating pyrochemical methods of separation together with Japanese partners, and preparing so-called inert fuel matrices that can be used for transmutation experiments mainly with CEA (France), NRG (Netherlands) and SCK (Belgium). A special “Minor Actinide Laboratory”, dedicated in September 2002 and built over the preceding 5 years, will allow ITU to be one of the few places in the world able to handle measurable (gram) quantities of Am and Cm.

In nuclear chemistry the research has evolved in a number of ways over the last 20 years. The physical characterization of nuclear material has developed into a field of “nuclear forensics” in which material coming to the Institute can be identified with respect to its composition, its age, and even where (and how) it was produced. With the demise of the Soviet Union in the early 1990s and the increase in illicit trafficking of nuclear material this capability became publicly well accepted, and ITU has now an important role developing new methods of analysis and interacting with a variety of agencies, including the IAEA and EUROPOL. Naturally, this capability is also of great interest for detecting radioactivity in the environment and a separate programme on this aspect was established some 10 years ago. With the expansion of the EU in 2004, legislation requires that the new countries monitor the radioactivity in the environment, so that there is a crucial role for ITU in training people in the related instrumentation and techniques in the years ahead.

The capabilities and competences of ITU have proven successful also in the market place. Since the mid 1980s ITU has succeeded in generating revenue, especially with the technology of the hot cells, and the “external income” now ac-

counts for some 15% of the annual budget. Work ranges from industrial contracts for the examination of irradiated fuel, to contracts with the Japanese for advanced fuel processing, to shared-cost actions with consortia of Government funded agencies.



Analytical capabilities are also of crucial concern in “safeguards” and ITU continues to play an important role in developing methodologies for safeguards analysis. These capabilities led to ITU being responsible for the establishment and operation of the “on-site” laboratories monitoring the flow of fissionable nuclear material at the reprocessing plants in France (at La Hague) and in the UK (at Sellafield). Funds for this operation come from DG TREN.

A rather unusual “spin-off” of the chemistry programme has been the development of short-lived radioactive alpha emitters (such as ^{213}Bi) for use in the treatment of cancer. This field of alpha-immunotherapy has developed rapidly in various places and ITU is well positioned to play a role in the future. The great advantage of alpha emitters is that they are powerful over a short range, and thus capable of killing tumours with relatively little damage to surrounding tissue. Of course, the choice of alpha emitters and the method of transport to the tumour (via chelating agents) is by no means trivial, but such a programme, in collaboration with a number of hospitals, is showing success and corroborates the special competence of ITU in the nuclear field.

On February 24, 1986, a colloquium with leading scientists in the field was held in honour of Roland Lindner, who had reached the age of retirement, and the new Director was Jacques van Geel, former collaborator of Eurochemic in Mol. During his tenure at ITU, Jacques van Geel succeeded in diversifying the work programme. In particular, programmes involving safeguards and actinides in the environment were started. Considerable progress was also made in obtaining industrial contracts for work on irradiated fuels in the unique hot cells at ITU.



Gerard H. Lander, Jacques van Geel, Roland Schenkel

Jacques van Geel retired in February 2000 and was succeeded by Roland Schenkel, who had started his scientific career in one of the ITU-laboratories in the seventies, and then went on to the Euratom Safeguards Directorate in Luxembourg for many years before returning to ITU as Head of Programme Office in 1994. In April 2002, Roland Schenkel was promoted to Deputy Director General of the JRC and moved to Brussels. His successor is Gerard Lander, former Head of the Actinide Research Group at ITU.

With forty years of experience and excellent equipment, with an increase in staff of 15% and rejuvenated research teams of collaborators from 15 countries (soon to be 25!), the European Institute for Transuranium Elements is well prepared to tackle the numerous challenges foreseen in the field of transuranium research under the recently passed 6th Framework Programme of the European Commission within the years to come.



***H-E. Schmidt
G.H. Lander***

nuclear safeguards

The nuclei of uranium and plutonium are fissile. The fission of this nuclear material releases large amounts of energy. This energy can be used for electricity production or for nuclear weapons. From the early days of commercially using nuclear energy it was clear that mechanisms were needed to assure that nuclear material intended for electricity production could not be used otherwise.

In the Euratom Treaty (Chapter 7, Article 77), the signatory states entitle the European Commission to verify that nuclear material is not diverted from its intended (peaceful) use. On a world-wide scale, the common will of the international community to prevent the proliferation of nuclear weapons has been expressed in the Non-Proliferation Treaty. Verification of compliance with the treaty obligations is a key element of these treaties and is achieved by the implementation of Safeguards. The safeguards authorities of DG Transport & Energy (DG TREN) (being in charge in the European Union) and of the International Atomic Energy Agency – IAEA – (being in charge world-wide) carry out the verification activities. The backbone of any safeguards system is measurements. In its function as the Commission's nuclear analytical reference laboratory, ITU plays a key role in the development, improvement and application of analytical methods for characterisation of nuclear materials. Thus, providing scientific and technical support to the Safeguards Authorities is an important task of the Institute. The main objectives are:

- Verification of the amounts of nuclear material in existing installations by means of highly accurate measurements of representative samples. *ITU has been involved in such activities for more than 30 years. Samples have been analysed at ITU on request of Euratom Safeguards. With the start of operation of the large reprocessing plants at Sellafield (UK) and La Hague (F), ITU developed and implemented and has been operating so called "on-site laboratories" since 1999, allowing the verification analysis to be performed in a dedicated laboratory on the site of the plant, thus avoiding the transport of a large number of samples. Measurement methods have been developed that provide high accuracy, minimize the production of waste and are simple and robust in the application.*

- Detection of clandestine nuclear activities through high sensitivity measurements of environmental samples and analysis of individual particles. *In the light of the experience gained in Iraq after the first Gulf war and in North Korea, the need arose to establish capabilities for detection of undeclared activities or for verifying their absence. ITU developed and implemented measurement methods for particle analysis. An ultra-clean laboratory was established to make sure that samples are not altered during preparation. The techniques allow to draw conclusions on the operation of the facility where the samples have been taken. Swipe samples are analysed on request of Euratom Safeguards and of the IAEA.*



nuclear safeguards

- Identification of seized nuclear material through nuclear forensic analysis. *Nuclear smuggling and illicit traffic of nuclear material was a new phenomenon coming up in the early 1990's. Through careful analysis of characteristic parameters of the material and comparison with known data, the origin of the material can be identified. ITU has done pioneering work in the analysis of seized nuclear material (the plutonium seized at Munich airport is the most prominent example) using its competence and expertise acquired in four decades of dealing with all aspects of nuclear material. (see article "Nuclear Forensic Science")*

In carrying out these activities, ITU is involved in international networks, where it takes in many cases a leading role. This includes the European Safeguards Research and Development Association (ESARDA), the IAEA's network of analytical laboratories for particle analysis and the International Technical Working Group on Combating Nuclear Smuggling. Bilateral co-operation with industry and with other leading laboratories (in Europe, the United States, Russia, etc.) in this particular field of nuclear safeguards are further strengthening ITU's position.

Co-operation with accession countries to the EU has been established, particularly in the context of combating illicit trafficking of nuclear material. Provision of training, delivery of equipment and the joint analysis of nuclear material seized in these countries are ITU's contribution to the fight against nuclear smuggling at the future eastern border of the EU.



C o n t a c t

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measurement of radioactivity in the environment

Environmental radioactivity under constant surveillance

The release of nuclear radiation into the environment can occur as a result of various human activities. These may involve nuclear weapons, the nuclear fuel cycle, medical applications or waste storage. The burning of fossil fuels also releases pre-existing natural radionuclides, which would otherwise remain trapped in the Earth's crust. As the European Union enlarges, such problems are likely to increase. In collaboration with national laboratories, the JRC is therefore active in the establishment of standardised sampling, analytical and data-management procedures for the continuous monitoring of radioactivity in the soil, air and water.

The distribution of radioactive fallout in the environment depends on a number of factors, including local weather conditions and the nature of the affected surface. In addition, the physico-chemical form of the radionuclides may vary, depending on the release and transport conditions, and on the properties of the element responsible.

A general distinction can be made between gases, aerosols and particulate materials. Particles with higher activity concentration, known as 'hot' particles, may result from atmospheric nuclear weapon tests or nuclear reactor accidents. This material is transferred to soil and water, either directly, or via vegetation and movement through other biological media. Consequently, the monitoring of environmental radioactivity necessitates the analysis of bulk samples from the biosphere, as well as of single microparticles.

Special facility

ITU set up the MaRE reference laboratory to provide scientific and technical support to the Transport and Energy DG for policy development. This is relevant to the implementation of the Euratom Treaty environmental radioactivity surveillance requirements. It is also significant for the framework of the Oslo-Paris Convention (OSPAR) strategy on the management of radioactive substances for the protection of the marine environment of the North-East Atlantic.

The role of MaRE is to carry out sampling and/or analytical campaigns, examine emergency samples and set up analysis methods for speedy detection of radioactive emissions in case of verification and radiological alarm. Standard methodologies for environmental monitoring of the terrestrial and aquatic environments are being developed with the aid of advanced analytical systems such as low-level background radiometric instruments and highly sophisticated mass spectrometers, housed in a special clean-room laboratory. Nanogramme (10^{-9} g) quantities of uranium, plutonium and other radionuclides can now be detected in environmental microparticles.

One notable success has been the introduction of a rapid analytical method for the monitoring of neptunium-237 in marine sediments by means of direct-current glow-discharge mass spectrometry (dc-GDMS). A sophisticated chromatographic technique for the monitoring of americium-241 has also been validated and applied to marine sediment core samples. Compared with the classical radiochemical separation of americium, this enables sample preparation time to be reduced from one week to just a few hours – permitting fast response in the event of emergency situations.

measurements of radioactivity in the environment

Europe-wide harmonisation

EU Member States have prime responsibility for ensuring compliance with the basic safety standards. However, article 35 of the Euratom Treaty also gives the Commission rights to access and verify the operation and efficiency of Member State facilities. Checking of sampling procedures, analytical methods, quality control programmes, data quality or data management may be undertaken:

- Where and when the Commission deems it appropriate;
- on invitation by national authorities;
- at the request of the European Parliament; or
- when one Member State requests verification in a neighbouring state.

Collaboration with scientists from Member States and Accession Countries is contributing to an EU-wide harmonisation of analytical procedures and the development of a common quality assurance/quality control programme.

Studies on radioactive environmental particles have been performed to determine their size (important in determining the risk of inhalation), chemical and isotopic composition. Furthermore, synchrotron radiation techniques have been exploited as a means of evaluating the oxidation states of radionuclides and their consequent bioavailability. Environmental radioactive microparticles stemming from different release scenarios are being characterised to create a database for use in case of radiological alarm.

A first trial sampling involving selected sites in existing and future Member States is scheduled to begin in late 2003 or early 2004.



C o n t a c t

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Atomic detectives

Combating trafficking of nuclear materials and associated environmental issues led to the development of a new discipline: nuclear forensic science. The JRC is a key contributor to European efforts in this field. Recognised as a centre of excellence by national and international policing bodies, the JRC has developed various techniques that allow identification of the origin of intercepted material, the route it could have taken and the probable intended application. With a team on standby at all times to respond immediately to a seizure, a first analysis can be delivered to the appropriate authorities within 24 hours of a sample arriving at the JRC.

The JRC undertakes many tasks in the fight against nuclear trafficking. It identifies the nature of seized materials and assesses the immediate associated risks. In addition, it determines the original source of a sample and its potential route – and offers an opinion on the probable intended use. The JRC also maintains an extensive database of commercial nuclear materials, together with information on seized illicit materials.

Experts at ITU develop and use a wide range of forensic science methods to address areas of concern related to illegal handling of nuclear materials and accidentally released nuclear materials.

Numerous successes

The JRC staff serve on the International Technical Working Group (ITWG) on Combating Nuclear Smuggling. ITWG organised a round-robin test between six laboratories in 1999, involving a simulated sample of smuggled plutonium. ITU was able to correctly identify the reactor type in which the fuel was originally irradiated and the type of plant where the material was subsequently reprocessed.

The JRC is equally accurate with “real life” samples. In 1997, two pieces of stainless steel contaminated with alpha particle radiation were found in a Karlsruhe scrap metal yard. ITU was able to make a unique identification of the source as the BN 10 fast breeder reactor in Obninsk, Russia. The trade in contaminated scrap metal is a relevant current problem in illicit trafficking control.

In another incident in 1994, a small lead cylinder discovered by police in a garage in Tengen on the Swiss-German border was revealed by ITU to contain plutonium metal, isotopically enriched to 99.7% weapons-grade plutonium 239 and mixed with traces of “red mercury”.

An item of luggage seized at Munich airport in the same year was found to contain a mixture of uranium and plutonium oxides. The powder was analysed at ITU and shown to contain three distinct components. Further analysis allowed a specific European manufacturer to be eliminated from inquiries.

More recently ITU has examined small radioactive “hotspots” about 1 mm in size that are occasionally discovered on the seabed and the beaches around Dounreay in Scotland – site of three reactors now being decommissioned by the UK Atomic Energy Authority. ITU showed that the particles were an aluminium-uranium matrix fuel used in a materials test reactor at the nuclear facility and were about 30 years old.

nuclear forensic science

Preserving the conventional chain of evidence whilst dealing with radioactive samples may be problematic. For example, lifting fingerprints from a sample is not compatible with taking a swipe for radioactive contamination. ITU nevertheless recently succeeded in making the first ever identification of a fingerprint on an object contaminated with isotopes emitting alpha radiation.

International collaboration

Of necessity, the JRC maintains close contacts with national and international law enforcement and customs agencies. ITU is recognised as a centre of excellence by Europol, and works closely with the German central police agency and the Federal Environment Agency (BMU), seeking to correlate standard forensic procedures with the special requirements of the nuclear scientist.

A programme of assistance for EU Accession States is in progress to combat trafficking within their borders. This involves advice and training, as well as the supply of appropriate equipment. On-the-spot demonstration exercises involving security services, custom officers, nuclear expert centres and high political representation have already been successful.

There is also close cooperation with other states, in particular those of the former Soviet Union, and with the IAEA and Euratom Safeguards Office (ESO). In addition, JRC has joined forces with IAEA to develop a model action plan for dealing with seized nuclear materials that can serve as a framework for developing national response plans. A fully developed version of the concept has recently been approved for use in the Ukraine.



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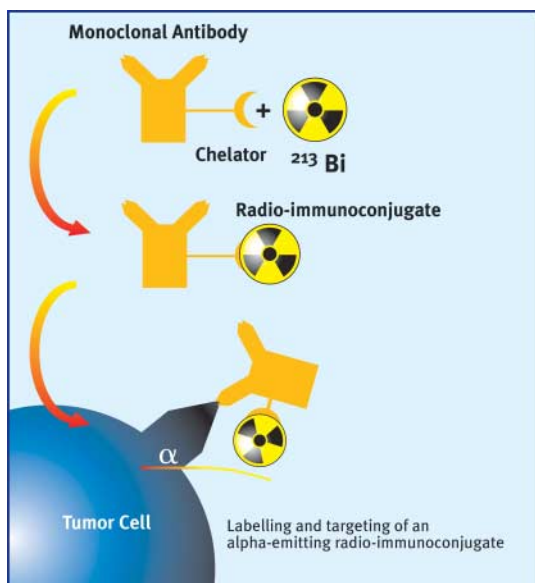
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alpha-immunotherapy

Radioactive “bullets” attack cancer at source

Radiation has been used in cancer therapy for many years. From the early 1980s, a new form of treatment based on aiming radioactive isotope “bullets” at diseased cells began to attract increasing interest. In the past, treatment mainly involved use of relatively low energy beta-emitters. More recently, isotopes emitting alpha particles have been recognised as more effective and selective against blood-borne cancers, widespread tumours and residual cells remaining after surgical intervention. Production of suitable alpha-emitters, their stable coupling to suitable carriers, and safe use of such tools in hospitals are important research goals for ITU.

The treatment of cancer by radio-immunotherapy involves injecting the patient with a radioactive isotope “bullet” connected to a specific cancer cell vector such as a monoclonal antibody, with the aim of selectively destroying targeted tumour cells. During radioactive decay, photons, electrons or even heavier particles are emitted and damage or kill cells along their trajectory.



Alpha emitters preferred

Radio-immunotherapy started about 20 years ago using beta-emitting radionuclides. These have a relatively low linear energy transfer (LET), so their decay energy is only partially absorbed by the cancerous cells; the remainder attacks healthy cells in an undesirable manner. As a result, research focused also on nuclides emitting alpha particles, which have high energy transfer values and release their energy over just a few cell diameters.

Recent experiments have proved alpha emitters to be very effective in destroying tumour cells. They are considered to be especially attractive for the treatment of blood-borne cancers and micro-metastatic tumours (where cancer cells are typically present throughout the body). Another likely area of use for alpha-immunotherapy is in treating the small numbers of cancer cells that may remain after high-dose chemotherapy or surgery.

A number of alpha-emitting isotopes have been considered, but most gave rise to various drawbacks that precluded large-scale implementation. The preferred option today is use of bismuth-213 (^{213}Bi), which has a half-life of 45 minutes – although the absence of a sufficient and clean production capability was initially a major barrier to exploitation. Actinium-225 (^{225}Ac), which has a half-life of 10 days and is the parent nuclide of ^{213}Bi , no longer occurs in nature and was obtainable only in small quantities from high level nuclear waste.

Supply of “bullets”

Researchers at ITU tackled the ^{213}Bi availability problem by developing and patenting different ways of producing ^{225}Ac . Presently, the most promising way is the irradiation of radium-226 with protons in a cyclotron. A dedicated installation for ^{225}Ac production has been built by the JRC in collaboration with the cyclotron department of the Research Centre Karlsruhe.

To improve the safety and reliability of isotope handling, a hospital-friendly radionuclide generator was developed, yielding 80 to 95% levels of ^{213}Bi recovery over several weeks.

The first European clinical trials of such alpha-immunotherapy started in April 2000 in Basel on patients with glioblastoma and, since early 2001, in Heidelberg on patients with non-Hodgkin's-lymphoma. The results vary from highly promising indications to cautious optimism, depending on the type and status of the disease. In New York, clinical trials are also continuing on patients with acute myeloid leukaemia. Special aspects of pre-clinical use of the treatment are being studied in Düsseldorf, Göttingen and Munich in Germany, Ghent and Hasselt in Belgium, and Nantes in France.

C o n t a c t

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ITU researchers push further exploitation

To evaluate the potential of using long-lived alpha-emitters, ITU embarked on the exploitation of innovative chelating molecules. Based on numerical models, promising compounds are synthesised and tested in collaboration with external partners in France and Finland. A new approach involving administering the radiopharmakon in two distinct steps, called “pretargeting”, which is known to increase both the specificity and speed of targeting, is also being investigated.

Targeted alpha particle therapy has now reached the initial proof-of-concept stage. Over the next five years, expansion of this approach into treatment of a variety of other tumour types and possibly non-malignant conditions is expected.

superconductivity of plutonium compounds - basic actinide research

Radioactive superconductors are a class apart

The discovery of superconductivity in the plutonium cobalt gallium alloy PuCoGa_5 was the first time that the phenomenon had been observed in a compound containing plutonium. As this finding does not fit with conventional theory, new scientific research is needed to account for the peculiar properties of this material. ITU is part of the team behind the discovery, which includes the Los Alamos National Laboratory and the University of Florida in the USA. Research into the electronic structure of the actinide series of elements is continuing and yielding novel insights into the nature of superconductivity, magnetism – and indeed of matter itself.

The superconductivity of PuCoGa_5 survives up to a surprising 18 K, placing it amongst the highest temperature intermetallic superconductors. In addition, its critical parameters, magnetic field and critical current above which superconductivity is destroyed are far above what conventional theory would expect. This enhanced superconductivity may be caused by radiation-induced damage to its own lattice structure that creates pinning centres within it.

If it were not for the inherent toxicity of plutonium compounds, PuCoGa_5 could be applied as a superconducting high-field magnet. However, knowledge gained about this compound may lead to the production of other combinations of actinide elements demonstrating similar superconductivity but with lower toxicity, and to a better understanding of unconventional superconductivity.

Complex electrons

ITU acts as a reference centre for basic actinides. It carries out research on radioactive elements in the periodic table beyond actinium (element 89). These elements owe their unique properties to the complexity of their outer shells of electrons. The resultant shielding confuses the usual predictions for electronic phenomena. One type of electron – $5f$ – resides in a kind of limbo, near the atom's surface, poised at the border between localised and itinerant electron behaviour – a consequence of wave-particle duality. The $5f$ electrons exhibit unusual properties: they become 'correlated', interchanging energy, and may lose their natural mutual repulsion – and, under certain conditions, become delocalised over the whole material structure.

Preliminary theoretical investigations suggest $5f$ electrons in plutonium play a crucial role in PuCoGa_5 superconductivity. However, the electronic structure of plutonium is not well understood. The element lies halfway between the light and heavy actinides and has a partially filled electron shell that enables many different valency states – its ability to bond to other materials – so that it forms a wide array of compounds. Depending on temperature, it assumes one of six different forms or phases, each with a different density and volume.

Because of its unpredictable behaviour and the need for stringent safety and environmental procedures when handling, much of the extensive characterisation work done on other metals has not been carried out on plutonium.

superconductivity of plutonium

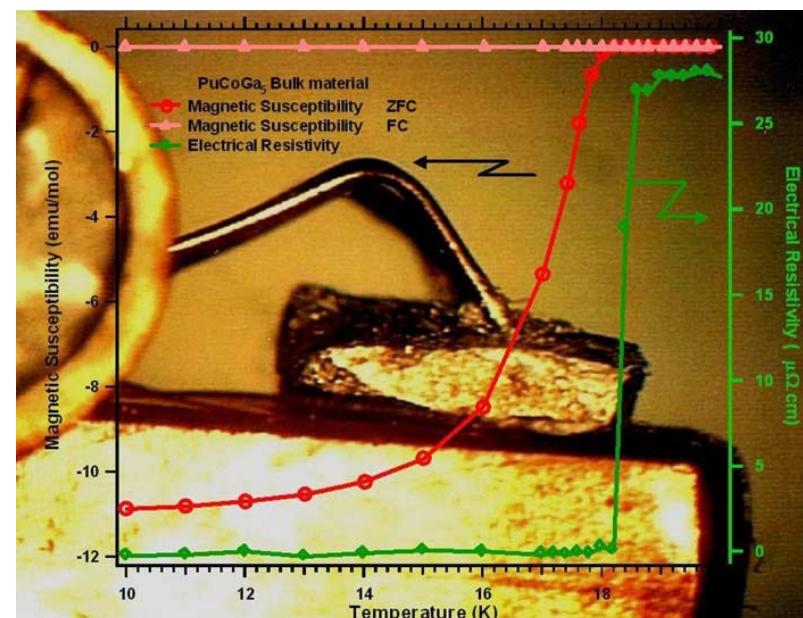
Nurturing the knowledge base

The need to develop nuclear fuels and treat nuclear waste spurs on efforts to characterise the actinide elements' structural and thermodynamic properties. ITU therefore researches their structural, magnetic, transport, and surface properties, aiming to account for the role of $5f$ -shell of electrons in all these aspects. The benefits of this particular project will come from a deeper understanding of superconductivity and correlated electron phenomena.

Development of a theory explaining this new class of superconductors has been boosted by the preparation of a second superconducting plutonium compound, identical to PuCoGa_5 , except that a rhodium atom replaces the cobalt atom. The new material's critical temperature is around 9 K. Data about its behaviour under variable conditions will help to modify and consolidate existing theory. A vital remaining question is whether superconductivity correlates with magnetically mediated superconductivity.

To encourage outside partners to join the collaborative work in this field, ITU opened an actinide user laboratory at the beginning of 2002, through the Commission's Programme of Access to Research Infrastructures. It is the only non-classified laboratory in Europe where broad research on sizeable quantities of actinides is conducted that offers access to external users.

Another initiative is the bi-annual school on "Actinide Science and its Applications" with 120 students attending the first two schools organised in 2001 and 2003.



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safety of nuclear fuel

Nuclear power plants currently generate some 30% of the electricity used in the European Union (EU) and Accession States. No substantial change of this situation is expected over the next 10 to 20 years. Nuclear safety is a prime concern of the public and will therefore remain a priority for the EU, particularly in view of the enlargement process. Regarding the licensing of advanced new reactor systems the goal is to enhance the safety features — including the nuclear fuel cycle — in comparison to the current generation of plants.

Advanced nuclear reactor designs range from evolutionary and advanced light water reactors (LWR) designs to even further advanced concepts, which go beyond LWR technology (e.g., high-temperature gas-cooled reactors, liquid metal reactors and on a very long-term even more innovative systems such as molten salt reactors).

From a sustainable development point of view, the weakest spots of present LWRs and fuel cycles is their poor capability to make full use of extracted uranium as an energy source. On the other hand, increasing fission exploitation of extracted

uranium entails production of plutonium and actinides and consequently implementation of more complex fuel cycles. Improvements in this respect are desirable from a sustainable development perspective to reduce further the amounts and volumes of long-lived waste.

The JRC is well equipped with suitable installations for this work; at the Institut for Energy in Petten (the Netherlands) the high flux reactor (HFR) reactor for test irradiations, at ITU hot laboratories for detailed post irradiation examination of fuel, thermophysics laboratories with high tempera-

ture/high pressure facilities and special laboratories for advanced fuel fabrication. The JRC has also a long and recognised tradition of collaborative R&D in the Reactor Safety field and e.g. in the development and use of the Fuel Performance Modelling code TRANSURANUS, where information exchanges take place in user-groups or workshops organised on a regular basis (see separate article). Furthermore ITU participates in the OECD Halden reactor project, in the IAEA FUMEX-2 exercise and in the development of the International Fuel Performance Experiments (IFPE) database (coordinated by OECD/NEA and IAEA). Many other projects are contractual works for nuclear companies (Framatome ANP, BNFL, Westinghouse, Belgonucléaire, CRIEPI etc.), engineering companies, service vendors (through networking and joint projects), nuclear regulators and technical safety organisations, other national and international organisations.

ITU's mission relative to the nuclear fuel research is to contribute to European efforts to increase the safety and useful life of nuclear fuel in commercial power stations. The programme comprises four major issues:

1. In-pile fuel behaviour with the following tasks:

- structural investigations and basic studies of fuel at high burn-up
- performance of high burn-up fuels
- fission product behaviour and interaction of structural materials under accident conditions

Severe accident cases with a core loss of geometry are investigated in the so-called COLOSS (COre LOSS) shared cost action program in a large network with numerous partners. ITU's contribution was to examine the dissolution of irradiated high burn-up UO_2 or MOX fuel by molten Zircaloy at temperatures of 2000°C. The figure shows the equipment used for these tests.

The metallographic examination clearly showed 2 factors: firstly the cracking in the irradiated MOX resulted in a more rapid break-up and dissolution of the fuel. Secondly the fission gas evolving from the fuel results in mixing of the melt.



safety of nuclear fuel

2. High temperature properties of irradiated fuel, mainly focussing on:

- thermal diffusivity and thermal conductivity of nuclear fuel
- source term studies (Knudsen cell)

3. The Transuranus code allows a detailed description of the fuel rod behavior such as:

- MOX fuel under normal operation
- UO₂ fuel at very high burn-up including transient conditions
- implementation of refined mechanisms for fission gas release and fuel swelling

4. Fabrication of advanced fuels including:

- oxides and nitride fuel fabrication processes
- improved MOX or Th based fuels

The research programmes include irradiation experiments in experimental and commercial reactors; the major projects being:

- THORIUM: instrumented ThO₂ pins are irradiated in the HFR in Petten and the KWO reactor in Obrigheim to study the fuel properties and their in-pile behaviour.
- MICROMOX to study the influence of Pu distribution in MOX fuel on fission gas release.
- OMICO, a low burn-up experiment (irradiation in BR2, Mol) to look at the fission gas release onset in different microstructures. The microstructural and Pu distribution effects are of particular interest.
- NFIR to compare heterogeneous and homogeneous MOX, irradiated to high burn-up in Halden.
- SMART irradiation in HFR Petten of three fuel pins, two pins consisting of MOX fuels with very high Pu content (up to 45%), manufactured using two different processes. A third pin is made of plutonium oxide embedded in an yttria-stabilized zirconia matrix. The target burn-up is 6-8 at%.

These projects are generally carried out as network projects (only SMART is an internal JRC (ITU-IE) project) where ITU's contribution is the fuel fabrication and in most cases also the post irradiation examination of the irradiated fuels.

In the future ITU's activities on the safety of the nuclear fuel cycle will be part of the work programme of the network of excellence called **ACTINET** (Actinide Network), where also training and education in nuclear safety will be increasingly included with:

- Transfer of knowledge to Accession States and newly Independent States to ensure integration into common safety standards.
- Assistance in ensuring high safety levels in ageing plants and when extending fuel burn-up.
- Critical follow-up of safety aspects and fuel strategies for innovative reactor concepts.

The JRC will be involved in networks operated by other organisations, such as MICANET (the Michelangelo network for competitiveness and sustainability of nuclear energy in the EU) and in the Generation IV initiative of the US Department of Energy. EURATOM has been recently appointed as new member of the Generation IV International Forum (GIF). It will also participate in Research DG shared cost actions and thematic networks within the European Research Area.

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thermophysics and nuclear materials science

Measuring the conductivity of irradiated fuels

Reactor fuels used in modern nuclear power stations are irradiated at increasingly high burn-up to maximise energy output and minimise operational costs. Fission products and radiation damage affect the performance and thermal properties of the fuel rods; measuring thermal transport properties becomes very difficult and expensive in highly gamma-irradiated fuels. Therefore, a special laser-flash device was designed and successfully implemented by ITU, making it possible to perform systematic measurements of the thermal conductivity of irradiated fuel with high precision. Work is continuing to extend the application of these measurement techniques.

ITU in Karlsruhe, Germany measured the thermal transport performance of irradiated fuel as part of the reactor fuel safety project in the EU Fifth Framework Programme. Following an intensive research and development phase, the first laser flash (LAF-1) device is now operational, taking simultaneous measurements of thermal diffusivity (transient heat flow) and heat capacity of highly gamma-active reactor materials.

An experimental measurement database enables prediction of the operating temperatures of light water reactor (LWR) fuel accurately up to the upper limit of useful burn-up, helping ensure long-term safety of the new generation of European reactors.



LAF-1 is a remotely-manipulated device, shielded against gamma radiation. It uses a sophisticated system of fast pyrometers to measure the speed of propagation of small thermal perturbations produced by a laser beam. Its major innovative feature is the ability to take measurements of irregularly shaped or fragmented fuel samples.

A high frequency furnace heats the sample; a subsequent long laser pulse raises its temperature above that of the furnace. When the thermal brightness of the sample is sufficiently unaffected by emission/reflection of the furnace thermal radiation, a second, shorter laser pulse is applied to the front surface. A very accurate photodiode-based pyrometer detects the resultant temperature changes – only a few K – on the opposite surface.

Thermogram recordings are analysed by a mathematical model for the temperature pulse propagation in the sample. Thermal diffusivity and heat capacity, together with effective heat losses, are then calculated to a precision higher than 1 and 5%, respectively.

Need for new knowledge

Thermal diffusivity of high burn up fuels, formerly extrapolated from mathematical models, can now be measured directly. The ITU LAF-1 experimental database contains thousands of measurements on over 40 fuels – from non-irradiated to very high burn-up types. It is used to analyse the deterioration of thermal conductivity with burn-up as a function of irradiation parameters.

A complex, accurate mathematical formula for in-pile thermal conductivity of uranium dioxide (UO_2) and gadolinium-uranium dioxide has been developed from the database. This takes into account all the effects and structural changes induced by reactor burn-up.

The thermal conductivity of nuclear fuel decreases with increasing burn-up, due to the accumulation of fuel defects. These can be compensated for by decreasing the fission rate or by allowing the fuel to operate at higher temperatures. However, fuel properties must not be allowed to degrade to the extent that the fuel becomes unsafe. Whether this degradation rate remains constant during irradiation or decreases with the irradiation time was previously unknown.

ITU research shows thermal conductivity degradation eventually levels off. This is a breakthrough with important consequences for the introduction of recently developed very high burn-up fuels.

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Perspective on new fuels

Having analysed several kinds of UO_2 fuels, ITU is also studying uranium-plutonium mixed oxide (MOX) fuels. LAF-1 will be used for all modern types of fuel – such as inert matrix fuel – containing plutonium and minor actinides. This should help provide an effective option to considerably reduce the long-term radiotoxicity of high-level nuclear waste.

The need for such data is particularly important for newly proposed materials, where the changing thermophysical characteristics under irradiation are unknown. Results should hasten the use of new advanced fuels, if they are shown to be both safe and economic.

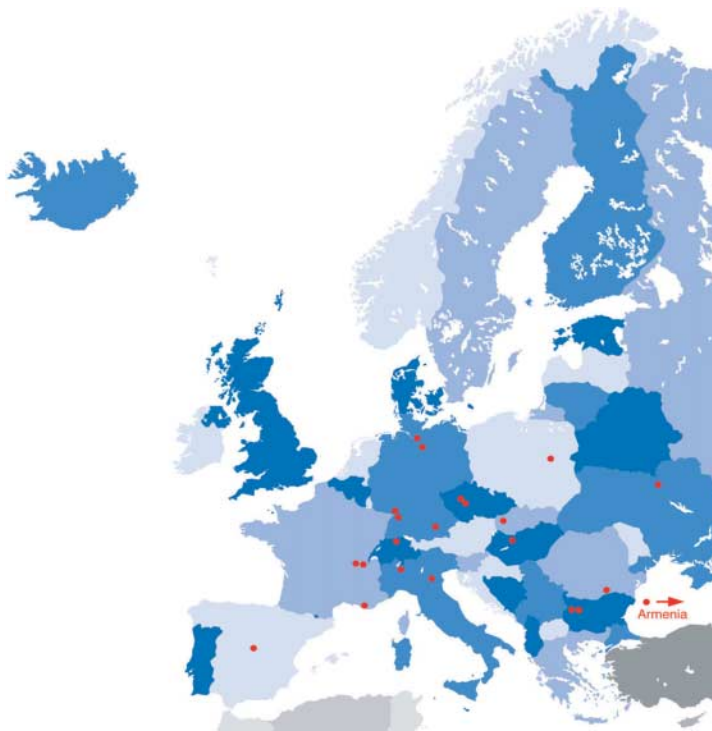
The next generation of LAF devices is already being planned in a project aiming to extend current capabilities. Given recent advances in laser technology, optics and computing power, a device (LAF-POLARIS) will operate under thermal and mechanical conditions closely mimicking those inside a nuclear reactor, with the measurements supplying very detailed information regarding thermal transport as a contour map of thermal diffusivity within the fuel rod's volume.

the transuranus code

Reliable modelling – a must for safe and economic nuclear fuel

Efficient and reliable fuel is vital for nuclear reactor technology. Safe and economic operation of fuel rods requires predicting behaviour and lifetime. An accurate description involves several disciplines, ranging from neutron physics, fabrication technology and fluid dynamics to material and computer science. It calls for computer codes describing general fuel behaviour. Fuel designers, research institutes and safety authorities rely heavily on this type of code since it requires minimal cost in comparison with that of an experiment or an unexpected fuel rod failure. ITU has set up TRANSURANUS as a long-term development and service project.

The TRANSURANUS code system describes and combines interacting phenomena by taking into account all relevant thermal, mechanical and isotopic properties of nuclear fuel – most of them changing during reactor operation or long-term storage. The code is supported by a comprehensive verification database.



Development and application

The development of the TRANSURANUS code began in 1973 at the Technical University Darmstadt, and in parallel from 1978-1982 at the Karlsruhe Research Centre (URANUS Code). The work was taken over by ITU in 1982.

The modular code is adapted to individual fuel requirements. Oxide, carbide and nitride fuels have all been modelled. In the 1980's, TRANSURANUS had been coupled with the European Accident Code, which analysed a hypothetical 'fast breeder' reactor core accident. Current development is focusing on high burn-up models for light water reactors and a version for Russian-type VVER pressurised water reactors.

Industry applies the code both to the design of new fuel rods and for safety reports required by licensing authorities. Criteria such as maximum temperatures, internal gas pressure, cladding deformation and oxidation are evaluated in a large range of conditions.

TRANSURANUS code users receive a manual, training courses and a license agreement. The TRANSURANUS research network is an informal users group that meets regularly to discuss problems and to define future priorities. The map shows the location of the users throughout Europe.

In the last decade, a growing database of well-documented fuel rod irradiations was set up and used for verification of the code. The verification database covers a large number of fuel types and reactor conditions.

International cooperation

A major objective is to harmonise nuclear fuel licensing across current and future EU Member States. Various support projects, including the two FERONIA¹ schemes funded from the EU PHARE programme, have contributed to the application of TRANSURANUS to VVER reactors. In the frame of a co-ordinated research programme of the IAEA and the EU PHARE projects the code was released to ten organisations in eight different eastern European countries. Transfer of knowledge was supported by the subsequent PECO² and EXTRA³ projects.

PECO was a joint project between the JRC and research institutions in Bulgaria, Hungary and Slovakia. It involves analysing recent irradiations of VVER fuel, performed both in Russia and, independently, at the Organisation for Economic Cooperation and Development (OECD) test reactor in Halden, Norway. The use of TRANSURANUS within a reactor system code was studied to improve safety-margin assessment. A modern graphical user interface has also been developed as part of continuing improvements.

EXTRA is a shared cost action between the JRC and research institutions in Hungary and Slovakia. This project concentrates on behaviour of VVER fuel rods in accident conditions (loss-of-coolant or reactivity-initiated). It aims to model the behaviour of Zirconium-Niobium cladding alloy at elevated temperatures, characterised by oxidation, hydrogen pick-up and deformation.

1. Simulations of Fuel rod Thermo-Mechanical Behaviour.

2. Central and Eastern European Countries.

3. Extension of the TRANSURANUS Code Applicability with Niobium Containing Cladding Models.

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Future projects and outlook

Modern reactor fuel has proven reliable with a very small failure rate. Over the past 30 years, fuel rod failure rates have decreased by three orders of magnitude to about one defective rod per million. Simultaneously, steadily increasing discharge burn-up, new fuel designs and more flexible operation of nuclear power plants have called for tighter control over rod performance.

In the short-term, the project's objectives are related to high burn-up uranium dioxide (UO₂) fuel, in addition to UO₂ with gadolinium (Gd) and mixed uranium-plutonium oxide (MOX), relying on the numerous instrumented irradiations in the ever-growing database. The mid-term objective is to go deeper into micro-structural details of the behaviour of nuclear fuel and cladding under various conditions, made possible thanks to refined micro-structural examinations, and improved computer power.

The long-term objectives of the TRANSURANUS project deal with the destruction of both excess plutonium and minor actinides, making more radical fuel design developments necessary. Associated research and development efforts focus on obtaining and characterising compatible inert matrices that can sustain irradiation conditions.

radioactive waste management

The issue of radioactive waste dominates public opinion and the European Commission supports the efforts of Member States in assuring the safe disposal of radioactive waste. Scientists from ITU are examining two main waste management options. One is to identify ways of significantly reducing the amount of long-lived radioactive material that will need to be disposed of through partitioning and transmutation, thereby shortening the very long times for which such waste must be stored safely. The second is to improve understanding of the behaviour of spent nuclear fuel subject to extended interim storage – several hundred years – or to final disposal in a geological repository, where detailed knowledge of the fuel behaviour under these conditions is required.

Spent fuel and high level radioactive waste contain an important amount of long-lived radionuclides, which means that the safety of disposal of such waste must be assured over very long time periods. Partitioning and transmutation aim at reducing this amount, through chemical separation of the radionuclides, followed by recycling them in reactors or “burning” them by neutron capture or fission (transmuting them into short-lived radionuclides). These are, therefore, valuable waste management options.

ITU is also looking into spent fuel characterisation for long-term intermediate storage or direct disposal. Safety-relevant data on the corrosion and dissolution behaviour of waste under realistic conditions are of utmost importance in determining the radiotoxic potential and assessing the consequences of such storage for up to several hundred years.

In this context, ITU is determining the dissolution behaviour of real high burn-up spent fuel. After about 500 years’ storage, the radioactivity of the spent fuel stems mainly from alpha decay, so alpha radiolysis plays a key role. It damages the structure of the fuel and influences its dissolution behaviour. To investigate the influence of radiolysis on spent fuel dissolution, ITU prepares and examines samples of uranium dioxide containing different concentrations of short-lived alpha emitting actinides (highly radioactive elements).

ITU also studies the behavior of spent nuclear fuel in long-term storage conditions and evaluates new concepts for nuclear waste management. The Institute focuses on methods for reducing the quantity and radiotoxicity of highly radioactive waste, by separating out the long-lived nuclides and fabricating them into fuels and targets for transmutation.

Policy

The research programme on nuclear energy is implemented mainly on the basis of Article 7 of the EURATOM Treaty. The duties of the Commission resulting from the Treaty, as well as the expertise required by policies and actions developed by concerned Directorates-General, are the basis for the JRC nuclear programme.

In most countries with nuclear power programmes, research is conducted to find suitable underground geological sites for disposal of high-level radioactive waste. Good progress has been made in this endeavour. The JRC’s work supports the Member States in their efforts to ensure the safety of geological disposal of long-lived and high-level radioactive waste, and to reduce the amounts of such material requiring disposal.

radioactive waste management

Networks

In the partitioning and spent fuel characterisation fields, the JRC participates in the networks in the EU and worldwide, not least through the shared cost actions of the Euratom research framework programme. Major partners of ITU include: SCK-CEN in Belgium; the Commissariat à l'Énergie Atomique and Electricité de France in France; the Forschungszentrum Karlsruhe, Jülich and Kernkraftwerk Obrigheim in Germany; ENEA in Italy; NRG in the Netherlands; CIEMAT and ENRESA in Spain; Chalmers University and SKB in Sweden; Reading University and BNFL in the UK; NRI/REZ in the Czech Republic; the Paul Scherrer Institute and the National Association for the Storage of Radioactive Waste in Switzerland; CRIEPI in Japan; and KAERI in Korea.

Enlargement actions

Research on radioactive waste management is of high relevance for Accession States. Organisations in these states are already beginning to work with the JRC. In the Czech Republic, for example, NRI/REZ participates in a European network on pyroprocessing.



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the minor actinide laboratory

About Partitioning & Transmutation

Nuclear waste management is one of the main priorities of the EURATOM 6th Framework Programme. The European Commission is therefore committed to research for the development of safe solutions in that field.

Partitioning and transmutation (P&T) is a suggested option for reducing the inventory of long-lived nuclear wastes. The aim is to partition – chemically separate – some of the important radionuclides present from the other materials in nuclear fuels and then to transmute them, to produce shorter lived or more stable nuclides.

An attainable goal is now considered to be a reduction by a factor of 100 of the radiotoxicity of the heavy elements of the present energy cycle when both the plutonium and the transuranic waste are separated and recycled. This would drastically shorten the period over which the radiotoxicity of the total waste exceeds that of “natural” reference (uranium ore). For current Light Water Reactors, this period is over 100 000 years. Transmutation could decrease this to several hundred years, a timescale much more compatible with our confidence in the reliability of the civil engineering used in waste storage.

To achieve this goal, research is done in a number of organisations, mainly in Europe, USA and Japan. At ITU, the work is concentrated on the development of advanced partitioning techniques (aqueous methods and pyroprocessing), of materials properties, and of novel techniques for the fabrication of fuels to be transmuted.



Fuels and targets fabrication for transmutation

As an example of these specific developments, the Minor Actinide Laboratory (MA-lab) of ITU is a unique facility for the fabrication of fuels and targets containing minor actinides such as americium and curium. It is of key importance for P & T research in Europe. It will be dedicated to the fabrication of minor actinides containing materials, either for the production of test pins for irradiation experiments and subsequent materials property determinations, or for the fabrication of ceramic samples designed for the long term conditioning and storage of actinides.

The MA-lab consists of ten cells forming two separate chains. The main chain consists of 7 cells. Its protection wall to shield the operators from the gamma and neutron radiation emitted by the isotopes of these elements, have 50 cm water and 5 cm lead as protection at working level and 10 cm polyethylene and 2 mm lead above. The second chain consists of 3 cells behind a protection wall of 10 cm polyethylene and 5 mm lead.

Telemanipulators are used for normal operation. In addition, extensive automation with remote control and robots has been included in the design. However, the cells are in fact standard glove boxes that permit manual intervention in the absence of radioactive sources, in case of maintenance and repair.

the minor actinide laboratory

The fabrication in the MA-lab is based on advanced liquid-to-solid processes to avoid dust-formation and its accumulation in the cells, which would make manual intervention very difficult. The infiltration process is the reference process for the main chain. In this process, which has been developed for nuclear applications at ITU, the minor actinides are infiltrated into porous particles, which can be pressed directly into pellets, or infiltrated directly into porous pellets. The second chain enables production of free-flowing (thus dust-free) powders by SOL-GEL processing for direct compaction to pellets. This process will be limited to Am for technical reasons.

The facilities in the MA-lab permit the fabrication of fuel pins with a maximum length of 1 metre. State-of-the-art Tungsten Inert Gas welding is installed and the fuel pins can be examined with high resolution X-ray radiography.

The construction of the MA-lab has been funded by the Joint Research Centre of the European Commission. The design and construction has been made by ITU staff, with assistance of local and international companies. In the coming years it will be used for the realisation of international projects within the Framework Programmes of the European Commission and for the fabrication of fuel pins and conditioning samples for international clients.



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laser transmutation

Powerful lasers lead to lab-scale nuclear fission

The ability to generate powerful laser beams using desktop equipment makes it possible to initiate nuclear reactions without recourse to large-scale reactors or particle accelerators. ITU pioneered this technology and, in collaboration with several partner institutes, is researching the transmutation of various radioactive isotopes. Investigation of actinides and long-lived fission products promises potential solutions to nuclear waste disposal problems, and other studies could increase the accessibility of medical radiotherapies. ITU is also providing a solid grounding for young European scientists in modern nuclear physics.

ITU initially proposed the idea of using laser radiation to fission uranium in 1990. However, at the time, laser sources of sufficient power were not available. Within a few years, enormous strides were made in laser technology; the advent of chip-pulse amplification boosting intensities by more than a thousand times to levels of 10^{20} W/cm². This is equivalent to projecting the entire energy output of the sun onto an area of just 1/10 mm²!

When focused onto a tantalum metal target, the beam generates a plasma with temperatures of ten billion degrees (10^{10} K), comparable to those believed to have occurred around one second after the 'big bang'. If the resultant accelerated electrons are directed at a secondary metal target, they create a stream of gamma photons energised at 10 to 20 million electron volts (MeV) – more than sufficient to initiate nuclear reactions .

In conjunction with the UK Rutherford Appleton Laboratory and its large VULCAN laser system, the JRC first successfully demonstrated laser-induced fission of metallic uranium (uranium-238) in 2000. By 2003, similar success had been achieved with thorium-232, in collaboration with the University of Jena in Germany, using its table-top laser.

New waste treatment route

Recently, in the context of partitioning and transmutation strategies for nuclear waste management, emphasis has been placed on the long-lived fission products iodine-129 and technetium-99.

With a half-life of 15.7 million years, high radiotoxicity and mobility, iodine-129 is one of the nuclear industry's primary risk considerations. There are also problems with the handling of iodine – it is corrosive, volatile and highly mobile. Ideally, the iodine-129 released during nuclear fuel reprocessing should be isolated in a form that can be transmuted to stable products using nuclear technology.

A joint JRC and University of Jena publication announced the first successful laser transmutation of this isotope. Ongoing research indicates that it is possible to convert long-lived iodine-129 into iodine-128, which then decays with a half-life of 25 minutes to the stable inert gas xenon-128.

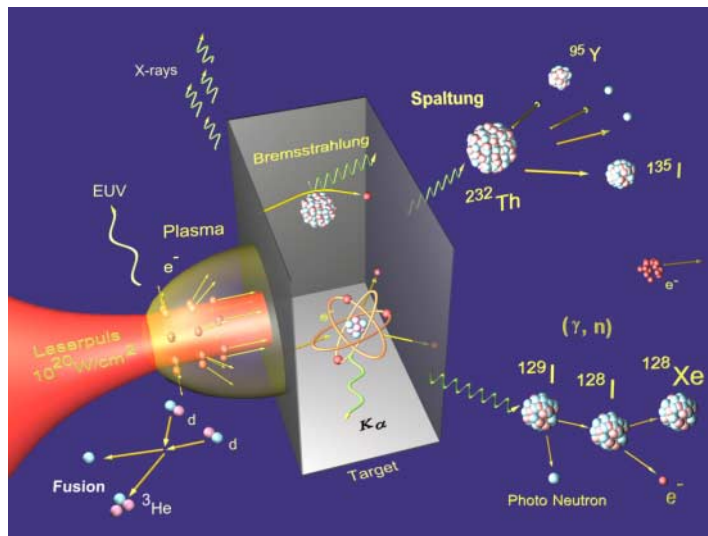
For technetium, which is particularly difficult to transmute, the petawatt power of facilities such as VULCAN remains essential.

laser transmutation

Healthcare potential

In the medical field, actinium-225 is a very promising candidate for treating cancers by means of alpha-immunotherapy. At present, however, actinium-225 must be produced in cyclotrons, meaning the radioactive product has to be transported in a timely fashion to treatment sites. The JRC is investigating the feasibility of transmuting radium-226 into actinium-225 by table-top laser. If power can be scaled up by some 100 times, it would then be possible to provide individual hospitals with their own on-the-spot production units.

Another potential application is the laser activation of micro-particles for cancer therapy. With appropriate host and starting isotope materials, high intensity laser irradiation can produce active particles suitable for the treatment of various forms of the disease. Current interest lies in the simultaneous activation of both β^- and β^+ emitters for therapy and visualisation.



Courtesy Institute for Optics and Quantum Electronics, University of Jena

Training opportunities

The JRC is committed to helping nurture the excitement of scientific discovery in future generations of nuclear scientists. In collaboration with international partners such as the University of Jena, the Universities of Glasgow and Strathclyde, and Rutherford Appleton Laboratory (RAL), sound training in advanced and industrially relevant aspects of nuclear technologies is provided to young science students, stimulating their intellectual curiosity and creativity. The JRC is also actively engaged in promoting research, publications, lectures and other forms of education and professional networking, and in encouraging the development of new techniques and equipment to advance nuclear research.

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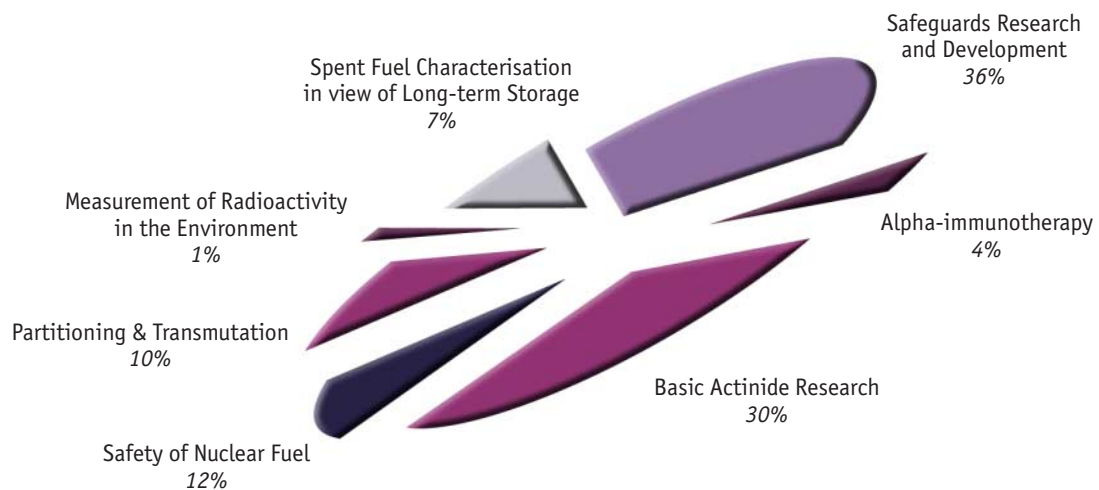
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resources

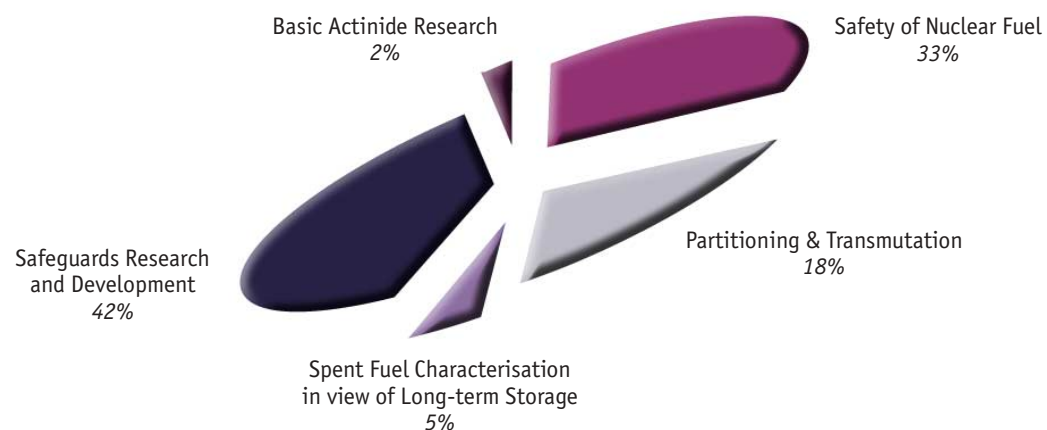
Institutional budget

Overall volume in 2002: 37.2 M€

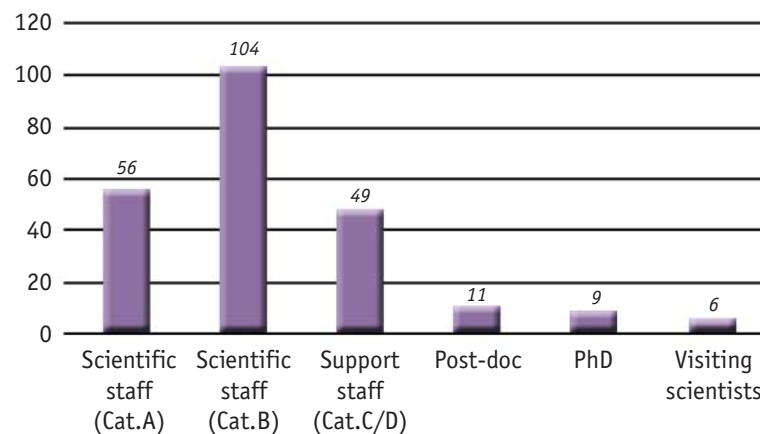


Competitive budget assigned to institutional activities

Overall volume in 2002: 7.2 M€



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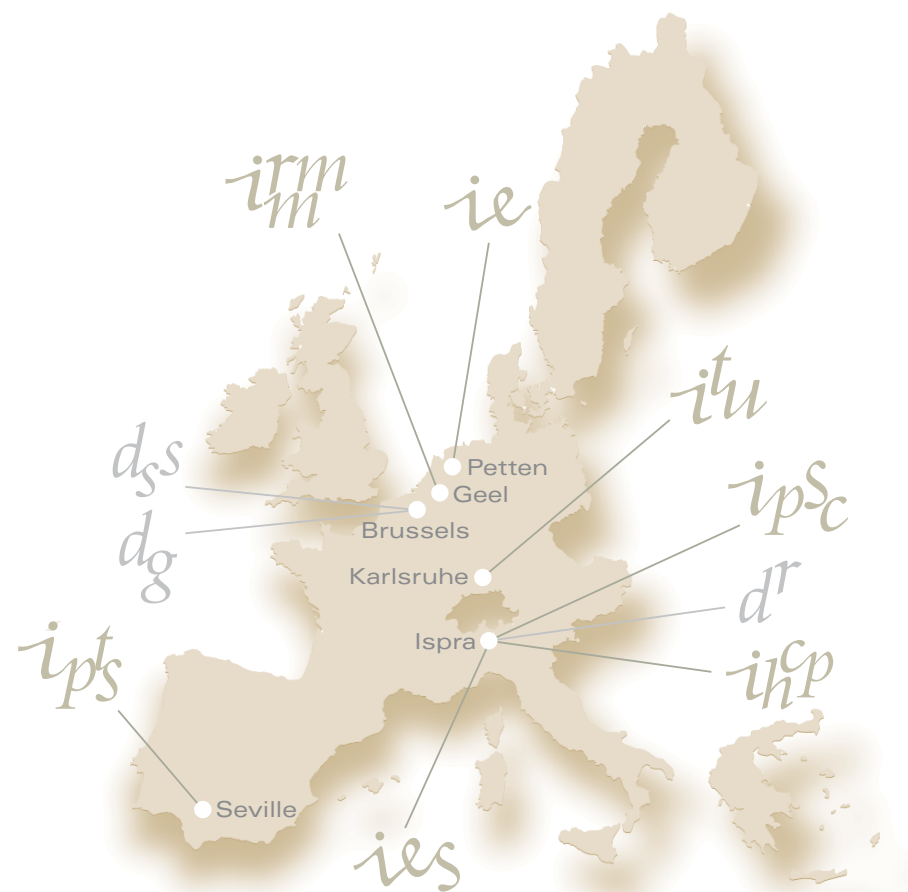
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